Control of heating power in ATP with virtual charts

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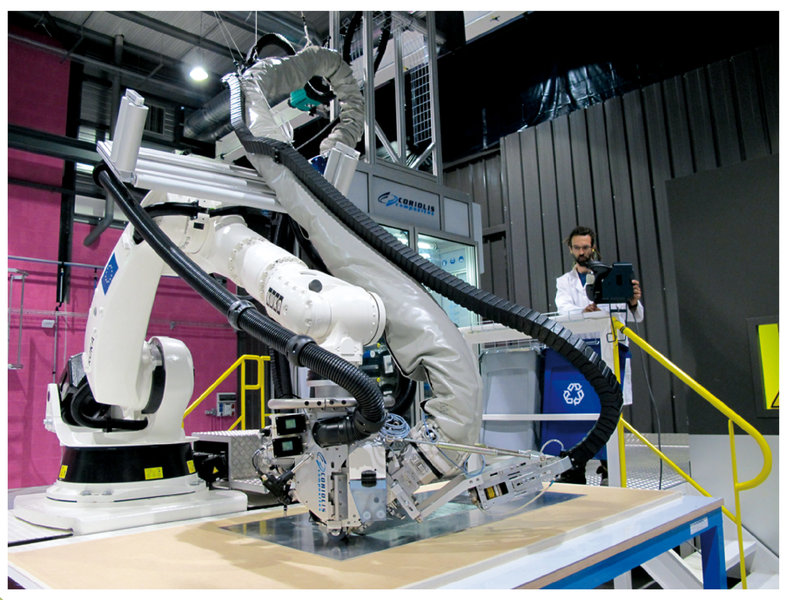
Problem



Using thermoplastic composites within an Automated Tape Placement process requires controlling drastically the temperature in order to heat the matrix enough to melt it, but not too much to avoid burning. Thus, to reach the optimal temperature within a given zone, we want defining the power of the source by

- integrating in the robot's control loop
- the temperature field
- computed for many values of different parameters

Method

Based on separated representation of the unknown, the *Proper Generalised Decomposition* (PGD) method allows to handle parameters as extra-coordinates, leading to virtual charts, without incurring the *curse of dimensionality*.

For example, instead of computing u on a 2D domain (x, z), at each time step (t) and for any value of a parameter (k), we write the unknown under the form

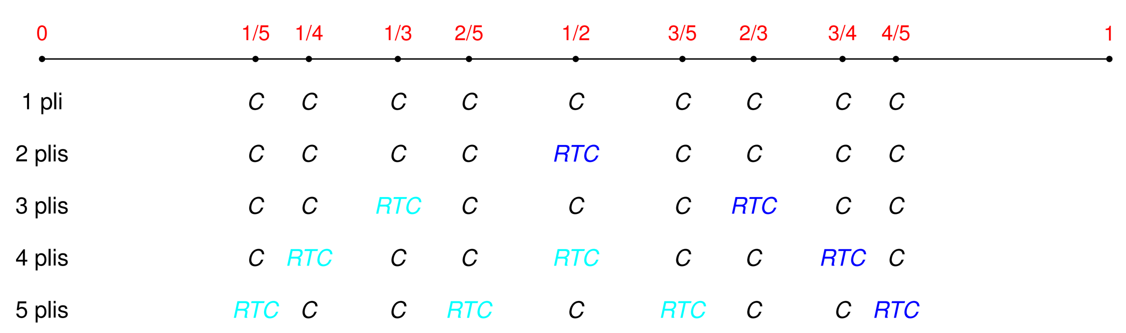
$$u(x,z,t,k) = \sum_{\alpha} X^\alpha(x) Z^\alpha(z) T^\alpha(t) K^\alpha(k).$$

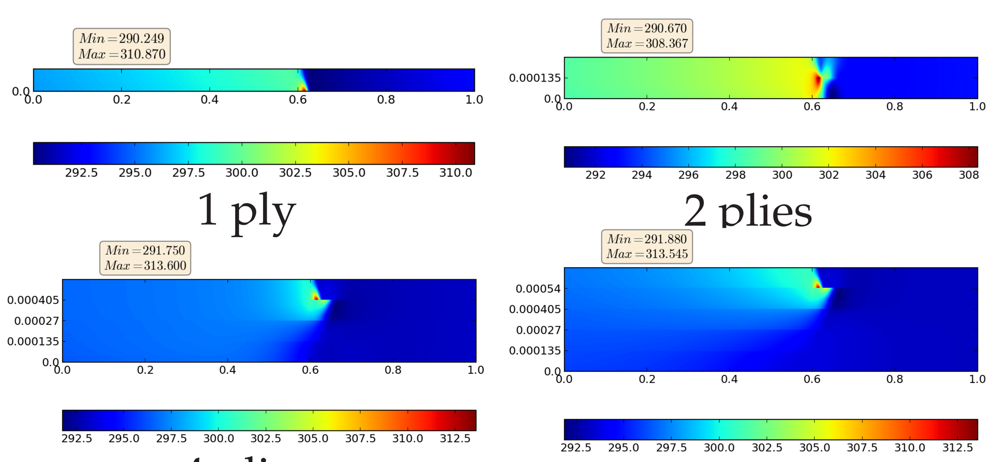
Then, assuming first functions are known, the approximation is enriched with a new mode $XZTK$ within a greedy algorithm:

$$u^{n+1} = \sum_{\alpha=1}^{n+1} X^\alpha(x) Z^\alpha(z) T^\alpha(t) K^\alpha(k)$$
$$= \underbrace{\sum_{\alpha=1}^{n} X^\alpha(x) Z^\alpha(z) T^\alpha(t) K^\alpha(k)}_{\text{known from initialisation or previous computations}} + \underbrace{X(x)Z(z)T(t)K(k)}_{\text{to be computed}}$$

of plies as coordinate

- Unitary domain in the thickness, discretised with the Least Common Multiple between the numbers of layers
- Double nodes at each possible interface
- Temperature continuity on fake interfaces (depending on # of plies) enforced with Nitsche's method





1 ply

2 plies

4 plies

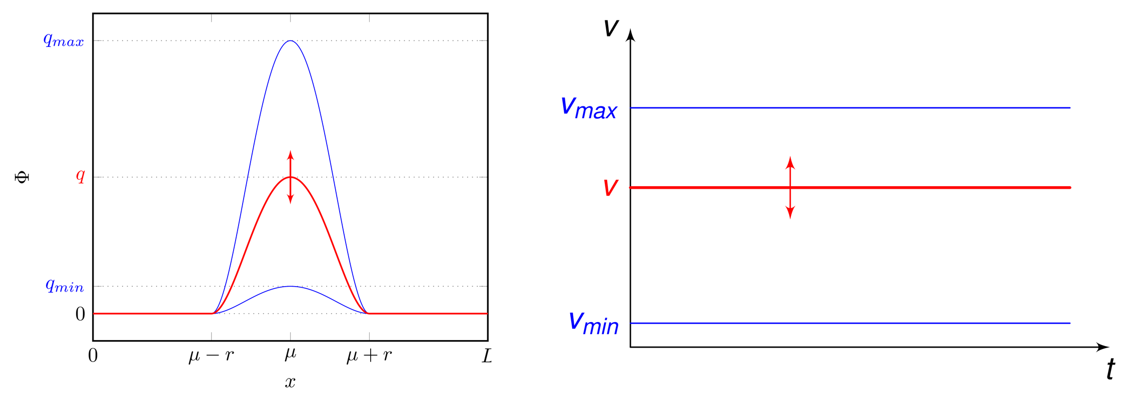
5 plies

Multi-parametric virtual charts

For a given trajectory, the robot's velocity is known: we want to determine the best associated power to ensure the optimal temperature. We assume a static solution is enough when acceleration is small, using a transient model otherwise.

Separating space, # of plies, power and speed:

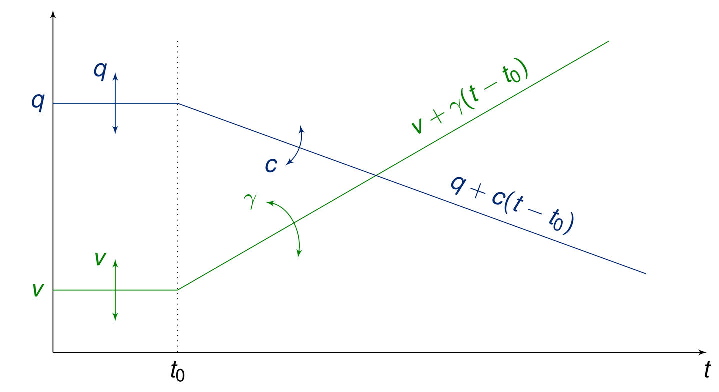
$$u = \sum XZPQV$$



Source and velocity parametrisation

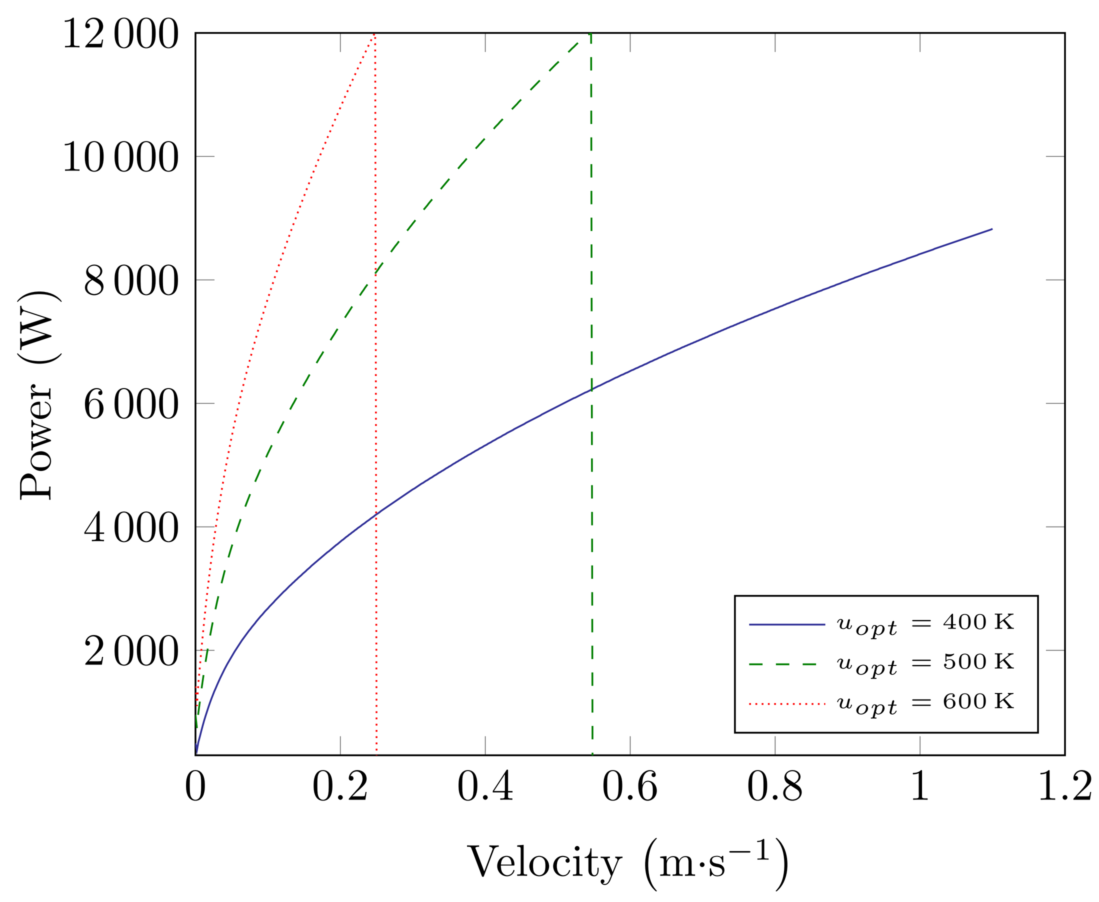
Separating space, # of plies, time, power, speed and acceleration:

$$u = \sum XZPTQCV\Gamma$$



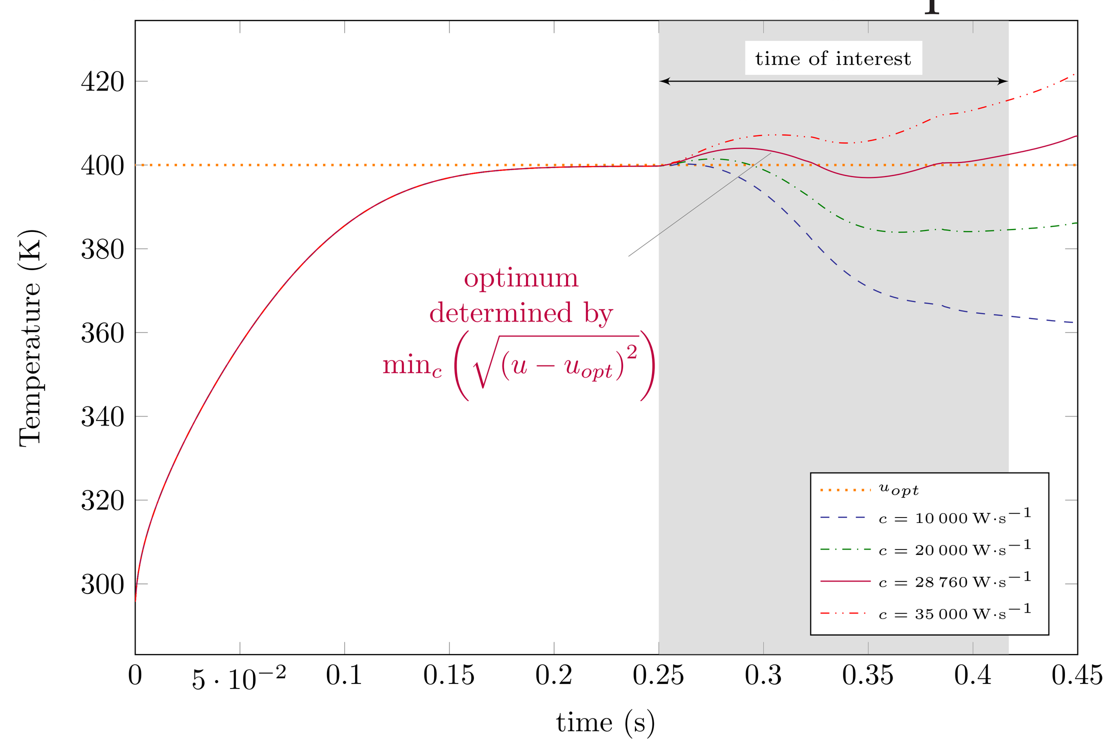
Power and speed parametrisation

Running the PGD algorithm leads to virtual charts depicted below



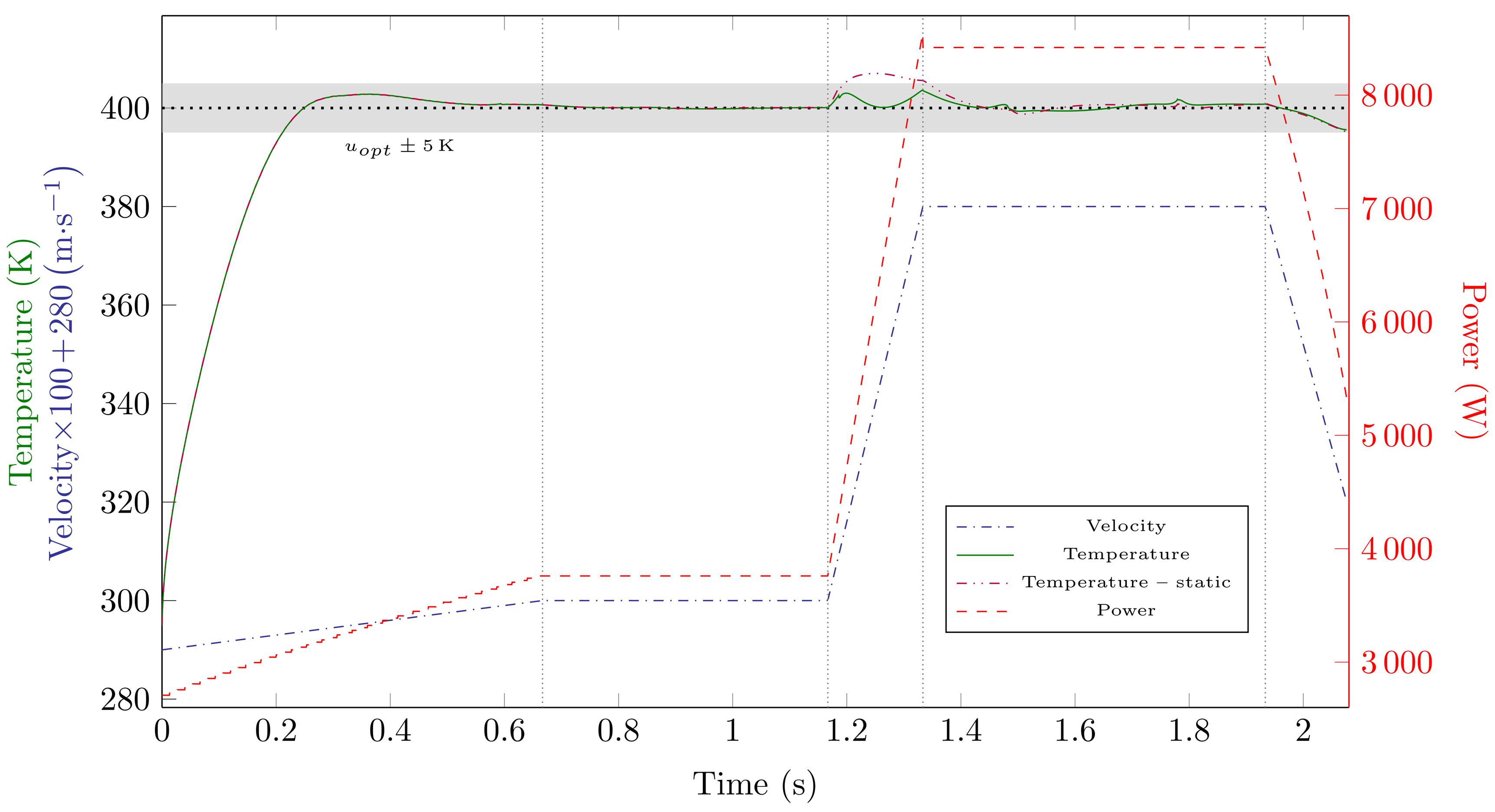
Process window when considering 8 plies

Within the control zone, for a given p, v and Γ are known. Then q is computed with static chart. The optimum c is solution of a minimisation problem



Choosing the power evolution

Numerical results



Temperature evolution within the control zone, using only static chart (purple dash-dotted line) or both static and transient (plain green line)

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